Multi-band Troposcatter Communications Systems

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Introduction

Troposcatter communications systems are used to provide radio connectivity between network nodes, but unlike most other types of radio communications techniques, troposcatter does not require a Line-Of-Sight (LOS) path between transmitter and receiver. As suggested by Figure 1, a tropo link is established when terminals point to a common volume in the troposphere and energy transmitted from one terminal is scattered toward the other. This generally results in a very low received signal power level that fluctuates randomly in time and must be processed by equipment specifically designed for tropo operation. As the world's leading provider of troposcatter communications products and systems, Comtech has consistently and successfully met this design challenge for customers around the world.

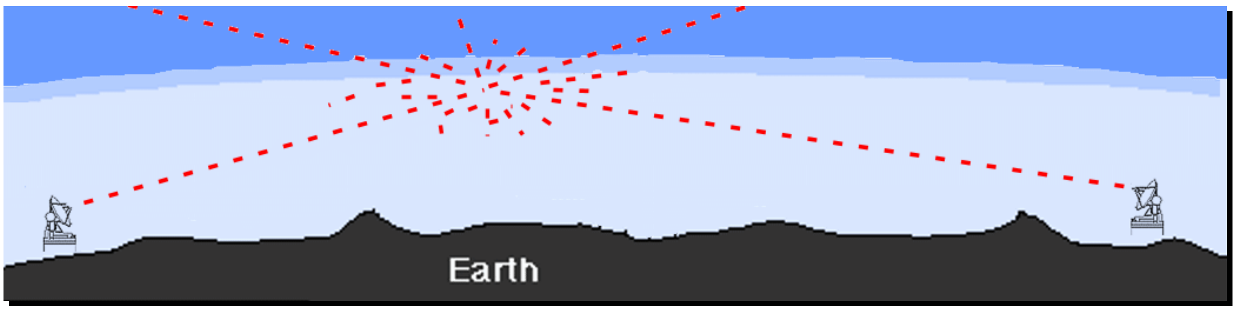

Figure 1. Troposcatter Communications

Most tropo equipment currently operates in the 4.4-5.0 GHz portion of the C-band. However with the increasing demand for high data rate communications and the crowding of the RF spectrum, some users are examining the feasibility of developing next generation tactical tropo systems that will operate in higher frequency bands as well as C-band, in particular the X, Ku and Ka frequency bands to determine if developing terminals capable of operating in one or more of these bands, in addition to C-band, would provide substantial benefits. This white paper is intended to support this evaluation by presenting the results of a comparative analysis of the expected link performance of C, X, Ku and Ka tropo systems.

Path Analysis Model for Predicting Tropo Link Performance

The earliest troposcatter communications systems were developed and installed in the 1950s, and since then a number of link performance models have been developed to support system design. The most widely used models have been developed empirically by assuming a basic structure for the fundamental tropo path link equation, and then curve fitting measured data to that structure. Probably the most widely used models are those published by the National Bureau of Standards (NBS) in NBS Tech Note 101 and by the ITU in ITU Recommendation 617-1. Comtech has developed a proprietary path analysis software package that is based on the models in Tech Note 101.

In both the NBS/Comtech and ITU tropo models, the basic form of the path equation for the median level of received signal power, P_r, on a tropo link can be expressed as follows:

1. $P_r = K + P_t - L_p(d, \theta, h) + G_f$ dBm

In (1), K is a constant, P_t is the transmitted power on the link (in dBm), and L_p is a frequency independent path loss factor (in dB) that is a function of the distance between antennas (*d*), the scatter angle (θ), and common volume altitude (*h*) - see Figure 2.

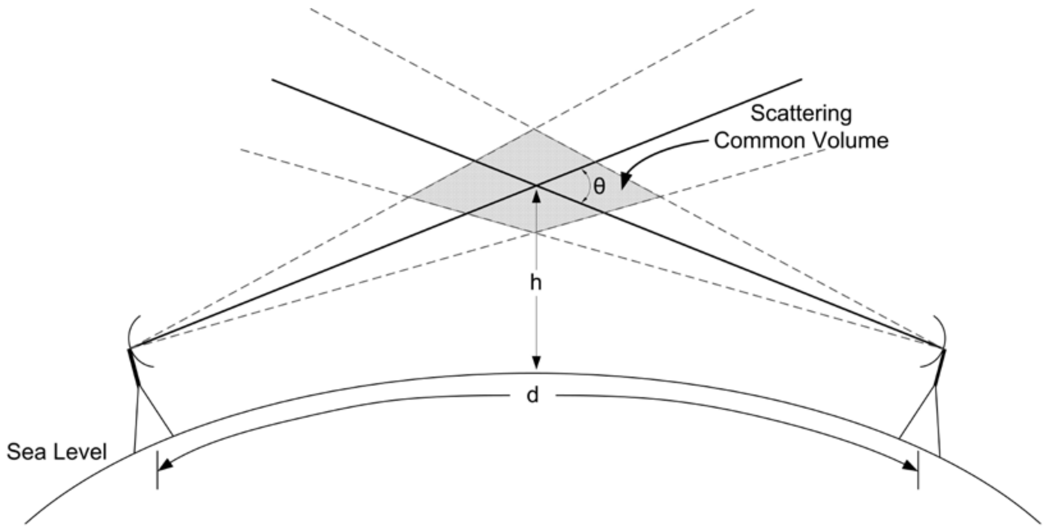

Figure 2. Tropo Path Geometry

L_p increases, and P_r decreases, with increasing *d*, θ and *h*. G_f consists of the path gain factors that can change with frequency and is given by:

2. $G_f = G_t + G_r - L_c(G_t, G_r) - q\log(f) - L_a(d, f)$ dB

To compare tropo link performance in different frequency bands, which is the current objective, it is sufficient to focus the analysis on G_f since it contains all of the frequency dependent factors in the tropo link equation:

- G_t, G_r: Transmit and receive antenna gains in dB.
- $L_c(G_t, G_r)$: Aperture-to-medium coupling loss in dB.
- $q\log(f)$: Frequency dependent portion of the path loss.
- $L_a(d, \theta, f)$: Attenuation due to atmospheric absorption, in dB. L_a will be a function of path length, scatter angle and frequency.

To assess the relative performance of tropo in the C, X, Ku and Ka bands, it will be necessary to establish the models to be used for calculating L_c, $q\log(f)$ and L_a.

> **Note**
> The analysis presented in this white paper does not address attenuation due to rain and other hydrometeors, which can have a severe impact on any radio system operating in the Ku or Ka Band. The inclusion of time-dependent, stochastic contributors to path loss, such as rain attenuation, would complicate the analysis significantly. Therefore the focus will be on frequency dependent path loss factors that affect median path loss, to keep the analysis analytically tractable.

Aperture-to-Medium Coupling Loss

Aperture-to-medium coupling loss, L_c, is a unique consideration for tropo links. It is an adjustment to overall link gain to account for the smaller common volume that accompanies reductions in antenna beamwidth (with a smaller common volume, less of the transmitted energy is scattered toward the receiver). Since antenna gain is inversely related to antenna beamwidth and is a readily available link parameter, aperture-to-medium coupling loss is generally expressed as a function of the transmitter and receiver antenna gains. The expression for L_c used in this analysis a Comtech-enhanced version of a CCIR model, which is given by equation (3).

3. $L_c = 0.07 \exp\left[0.055(G_t + G_r)\right] dB$

Tropo Path Loss Frequency Dependence Factor

The frequency loss factor in equation (2), *qlog(f)*,is taken to be *30log(f)* in the NBS/Comtech and ITU tropo models. When used to predict link performance at frequencies below 1 GHz, the *30log(f)* factor has generally led to results that are consistent with measured data, which isn't surprising since the tropo link equations used for the predictions were obtained by curve fitting data from links operating below 1 GHz. But that only confirms that the link equation, of which the *30log(f)* factor is a part, yields useful results as a whole. It doesn't necessarily confirm that the *30log(f)* assumption itself is an accurate general representation of how tropo path loss varies with frequency.

> **Note**
> The link models derived from data taken for frequencies below 1 GHz have been successfully extended up to operating frequencies of 5 GHz. But again, this does not validate the *30log(f)* assumption itself. It only confirms that the entire link equation that includes the *30log(f)* assumption can produce good results.)

As it turns out, the *30log(f)* formulation most likely overestimates path losses, especially at higher frequencies, and a different model needs to be considered for this analysis to estimate the sensitivity of path loss to frequency changes. Fortunately, ITU Recommendation P.452-13 provides a model that can be used. ITU-R P.452-13 contains path loss models for various propagation modes, to enable prediction of interference levels in microwave communications systems. The Recommendation includes a troposcatter transmission loss model for frequencies between 700 MHz and 50 GHz, and the model's frequency dependence is expressed as $25\log(f) - 2.5[\log(f)]^2$. By setting this expression equal to *qlog(f)* and taking into account the *30log(f)* frequency dependence in the NBS/Comtech and ITU models, one can estimate upper and lower bounds for q in the path loss factor $q\log(f)$, at the frequencies of interest for this analysis. The bounds that are obtained lead to the following as an approximation for the range of values for q:

4. $23 \leq q \leq 30$.

This range for q will be used in assessing the relative performance of C, X, Ku and Ka tropo.

Path Loss due to Atmospheric Attenuation

Atmospheric absorption of propagating electromagnetic waves is negligible at lower operating frequencies, but it increases with increasing frequency and is appreciable in the C, X, Ku and Ka bands. It is dominated by oxygen and water vapor absorption and expressible as

5. $L_a(d, \theta, f) = \gamma_{oo}(f)r_{eo}(d, \theta, f) + \gamma_{oo}(f)r_{ew}(d, \theta, f)$

In (5) γ_{oo} and γ_{wo} frequency dependent absorption coefficients for oxygen and water vapor, and r_{eo} and r_{ew} are the effective path lengths for oxygen and water vapor absorption. Chapter 3 of NBS Tech Note 101 provides graphs for obtaining values of γ_{oo}, γ_{oo}, r_{eo}, and r_{ew}

Comparative Analysis of Tropo at C, X, Ku and Ka Bands

The portions of the C, X, Ku and Ka bands that might be used for tropo are as follows:

- 4.4 GHz – 5.0 GHz (C-Band)
- 7.9 GHz – 8.4 GHz (X- Band)
- 14.4 GHz – 15.5 GHz (Ku-Band)
- 22 GHz – 24 GHz (Ka-Band)

To assess the relative performance of tropo links operating in these differing frequency ranges, a reference link having d = 60 km and $\theta = 0.1^{o}$ was analyzed at the highest frequency in each range. For the analysis, it was assumed that a 50% efficient, 3 meter diameter reflector antenna, which is equivalent to a Comtech Transportable Fast Link Antenna (TFLA), is used on each end of each link. Table 1 provides a summary of the frequency related gains and losses calculated using equations (3) and (5) and at the low, mid and high values of q given in (4).

Table 1. Comparison of Frequency Related Losses for C, X, Ku and Ka Bands

freq (GHz)	qlog(f)			Antenna Gain (dB)	L_c (dB)	L_a (dB)	frequency related loss (dB)		
	q=23	q=26.5	q=30				q=23	q=26.5	q=30
5	85.1	98.0	111.0	40.9	6.3	0.4	10.0	22.9	35.9
8.4	90.3	104.0	117.7	45.4	10.3	0.5	10.3	24.0	37.8
15.25	96.2	110.9	125.5	50.6	18.3	1.2	14.5	29.1	43.8
24	100.7	116.1	131.4	54.5	28.2	3.3	23.2	38.5	53.9

The shaded area in Table 1 indicates that path losses for C-band tropo will be less than for the other bands under consideration. Note however that there is less than 2 dB of loss in going from C-band to X-band under any of the conditions analyzed. Therefore it would be reasonable to expect that X-band would provide comparable performance to C-band in a multiband terminal. However one would not have the same expectation for Ku or Ka band: the performance loss from C-band would be 4.5-7.9 dB for Ku-band and 13.2-18 dB for Ka-band.

The higher frequency related losses for Ku and Ka band can be overcome in a multiband terminal if higher powered amplifiers are used, but the additional power required could be quite large. For example, if a 500W amplifier is used at C-band then 1.4 kW – 3.1 kW would be needed to provide equivalent performance at Ku-band and 10.6 kW – 31.7 kW would be needed at Ka-band (see Table 2). Therefore, the marginal cost of including Ku or Ka-band in a multiband tropo could be substantial if the same level of performance as C-band is required. For Ka-band, the expense is likely to be prohibitive. Note: 500W is the output power level for the Comtech Transportable Tropo Communications Terminal (TTCT) and therefore a good reference point for comparing with C-Band.

Table 2. Representative Output Power Requirements for Similar Performance at C, X, Ku and Ka bands

freq (GHz)	Output power required (Watts)		
	q=20	q=25	q=30
5	500.0	500.0	500.0
8.4	539.1	646.4	775.1
15.25	1408.9	2081.6	3075.4
24	10559.0	18283.5	31658.7

Summary and Conclusion

Extending the operating frequency of tropo systems beyond C-band into the X, Ku and Ka bands has been analyzed to assess the relative performance of tropo in these differing bands. The analysis consisted of factoring the basic link equation for a tropo system into frequency dependent and non-frequency dependent components, and then focusing on the frequency dependent parts to calculate relative link losses for C, X, KU and Ka band tropo. Based on this analysis, the following conclusions would be appropriate:

- While C-band would be expected to outperform the other bands considered, the loss in performance at X-band would be minimal. Therefore including X-band in tropo spectrum planning would be worthwhile.
- The expected difference in performance between C-band and Ku-band would be significant so it isn’t clear that Ku-band tropo would merit the cost.
- Adding Ka-band tropo would probably not be worth the cost increase involved for a given link.